AD-A063 254 NORTHEASTERN UNIV BOSTON MASS ELECTRONICS RESEARCH LAB F/G 22/2
MOTOR DRIVE SYSTEMS FOR SOUNDING ROCKET PAYLOADS,(U)
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MOTOR DRIVE SYSTEMS FOR SOUNDING ROCKET PAYLOADS

by

10 Richard L. Morin

15 F19628-76-C-0152

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14 SCIENTIFIC-[redacted] 2

11 Oct[redacted]978 12 27p.

16 2123 17 03

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Prepared for

Air Force Geophysics Laboratory
Air Force Systems Command
United States Air Force
Hanscom AFB, Massachusetts 01731

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-78- 0252	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MOTOR DRIVE SYSTEMS FOR SOUNDING ROCKET PAYLOADS		5. TYPE OF REPORT & PERIOD COVERED Scientific-Interim 6. PERFORMING ORG. REPORT NUMBER Scientific Report #2
7. AUTHOR(s) Richard L. Morin		8. CONTRACT OR GRANT NUMBER(s) F19628-76-C-0152
9. PERFORMING ORGANIZATION NAME AND ADDRESS Northeastern University Electronics Research Laboratory Boston, Massachusetts 02115		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63424F 21230303
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscon AFB, Massachusetts 01731 Monitor: Edward F. McKenna, LCR		12. REPORT DATE October 1978 13. NUMBER OF PAGES 27
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Planetary gearmotors; Tandem motors; Worm gear mechanism;

Geneva cam mechanism; Current limit control.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Presented is a summary of the design and development of a motor drive system, under Contract Number F19628-76-C-0152. The primary objective is a mechanism and control system to meet the requirements of the Multi Spectral Measurements Program. In general, the concepts are applicable to future sounding rocket payload motor drive systems.

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Details of a worm gear mechanism and two mechanisms utilizing geneva cams are described in this report. Tandem, planetary gearmotors are used to drive the mechanisms. The constant current motor control circuit provides redundancy and eliminates the need for mechanical limit switches. Test procedures and the operation of the mechanisms in the first two Multi Spectral Measurements Program payloads are also discussed.

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Mr. Norman C. Poirier of Northeastern University and Mr. Russell G. Steeves of Air Force Geophysics Laboratory were major contributors to the design of the MSMP motor drive systems described in this report.

Mr. Poirier is a Research Associate in the Electronics Research Laboratory. He designed the motor control circuit and was responsible for the selection and evaluation of electronic components. The innovative redundancy circuits are particularly significant to the successful operation of the motor drive systems.

Mr. Steeves is the Systems Engineer and Test Conductor for the MSMP. In addition to his system responsibilities, he designed the sensor module structure, including the door configuration and the control mechanisms. The sensor module underwent problem-free testing due largely to his thorough engineering and coordination efforts.

1.0 STATEMENT OF WORK

The subject of this report is the design, packaging and testing of reversible motor driven mechanisms and control systems to operate the sensor module doors on the Multi Spectral Measurements Program (MSMP) payloads. The motor drive and control concepts will be applicable to other sounding rocket payload systems.

1.1 DESIGN SPECIFICATIONS

A single stage Aries vehicle will boost the MSMP payload, which consists of a sensor module and a target engine module. At approximately 90 km. altitude the sensor module and the target engine module will be separated and individually controlled on different trajectories. After separation, the sensor module will be oriented such that the optical instruments will be pointed at the plume of the target engine as it proceeds through a number of burns during the course of its trajectory.

The 38-inch diameter MSMP sensor module is 89.62 inches long and has two hinged doors which protect the sensors during boost and descent. Each door is 80.75 inches long, spans 65 degrees, and weighs 47 pounds. A minimum travel of 115 degrees is required. Motor driven latches will be used to secure the doors in a closed position at the longitudinal separation joint.

Opening or closing cycles (doors and latches) must be accomplished in less than 30 seconds at altitudes above 100 km. Components must meet the following environmental specifications:

1. Temperature: $-10^{o}C$ to $+70^{o}C$
2. Altitude: 10^{-6} torr
3. Vibration: A. Sine Sweep: $\pm$ 20G, 20 to 2,000 HZ., three axes.

B. Random: 5G, RMS, for 60 seconds, three axes.

4. Shock: 50G, sawtooth, for 11 milliseconds.

2.0 DESCRIPTION

Sounding rocket payloads have provided many applications for motor driven mechanisms; including retractable nosecones, extended booms, reversible door systems, latches, and valve controls. Reliable control circuits and system redundancy are the major problems encountered with motor driven systems. Motors and mechanical limit switches are generally the single failure points. Tandem armatures on a single drive shaft provide the desired redundancy; and mechanical limit switches are completely eliminated in the system described in this report. A constant voltage circuit with adjustable current limiting is used to control the tandem motors.

The adaptability of the system was demonstrated when a late design modification to the MSMP payload required venting of the sensor module prior to the data portion of the flight. The vent door mechanism, as well as the instrument door and latch system, is described in this report.

3.0 MECHANISMS

A wide variety of drive mechanisms have been encountered in sounding rocket payload designs. Direct motor shaft drive is often practical; however, other applications have required worm gear mechanisms, ball bearing screw actuators, and rotating cams. One of the mechanisms described in this report uses a worm gear combination. Geneva cam concepts are utilized for the other two MSMP systems.

The basic geneva mechanism consists of a driver and a cam which can produce intermittent motion at various intervals. Figure 3.1 depicts an eight-point geneva mechanism. Rotation of the driver

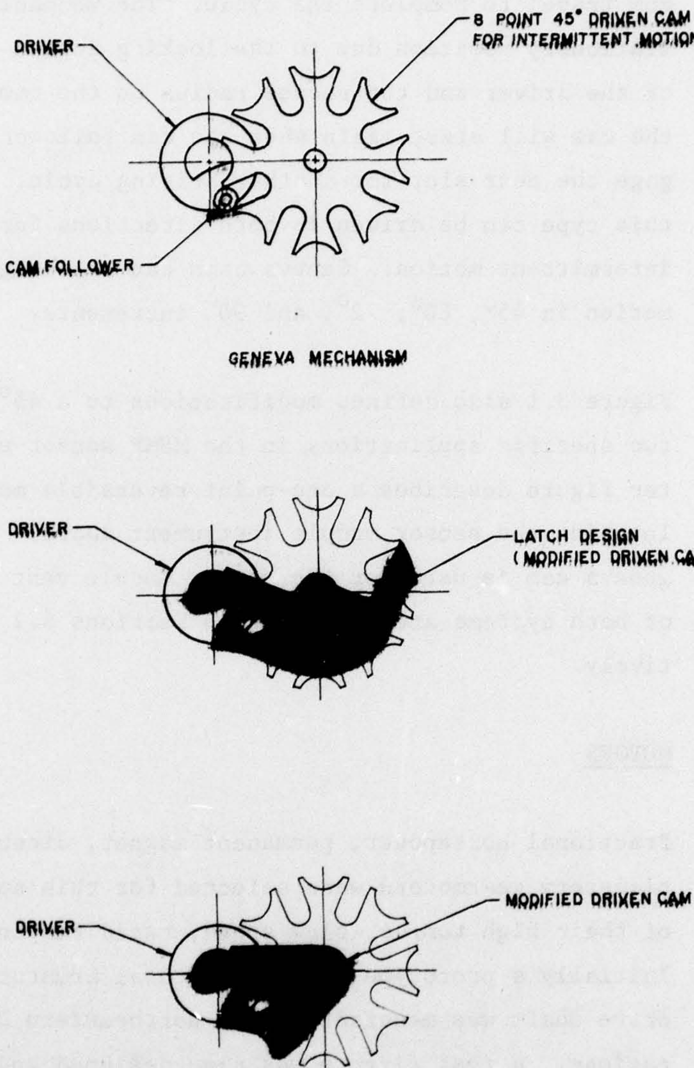

8 POINT 45° DRIVEN CAM
FOR INTERMITTENT MOTION
DRIVER
CAM FOLLOWER
GENEVA MECHANISM
DRIVER
LATCH DESIGN
(MODIFIED DRIVEN CAM)
DRIVER
MODIFIED DRIVEN CAM

FIGURE 3-1

causes the cam follower to engage the slot of the geneva cam, pushing on the side wall and rotating the cam. The cam follower is then gradually disengaged from the slot after a maximum travel to complete the cycle. The mechanism is now in a stationery position due to the locking action between the boss of the driver and the recess radius on the cam. Rotation of the cam will start again when the cam follower travels to engage the next slot for another driving cycle. Mechanisms of this type can be driven in both directions for reciprocating intermittent motion. Geneva cams can be designed for rotational motion in 45^{o}, 60^{o}, 72^{o}, and 90^{o} increments.

Figure 3.1 also defines modifications to a 45^{o} geneva cam for two specific applications in the MSMP sensor module. The center figure describes a one-point reversible mechanism used for latching the sensor module instrument doors. The two-point geneva cam is used for the sensor module vent door. Details of both systems are described in Sections 6.2 and 6.3, respectively.

4.0 MOTORS

Fractional horsepower, permanent magnet, direct current and planetary gearmotors were selected for this application because of their high torque, slow speed, rapid response, and small size. Initially a prototype motor, with dual armatures and a single drive shaft was manufactured to Northeastern University specifications. A test fixture was also designed and fabricated to check motor operation and control circuit characteristics. A geneva gear configuration, similar to the proposed MSMP latch mechanism, was selected for the test fixture.

Torque and speed tests were conducted on a dynamometer to evaluate the prototype motor before installation in the test fixture. Data from the test fixture confirmed calculated values, established current limit circuit parameters, and checked operation of the geneva

gear mechanism.

Procurement problems were encountered with the original manufacturer and alternative sources were investigated. Motors for MSMP were eventually purchased from TRW Globe, Inc. Speed vs. torque and current vs. torque curves from Globe were used to select the MSMP motors. Specifications for the door drive and the latch mechanism motors are detailed in Table 4.1.

5.0 CONTROL CIRCUITS

Mechanical limit switches are generally used to control motor driven mechanisms. Special mounting provisions are required for the limit switches, which are inherently difficult to adjust and present redundancy problems.

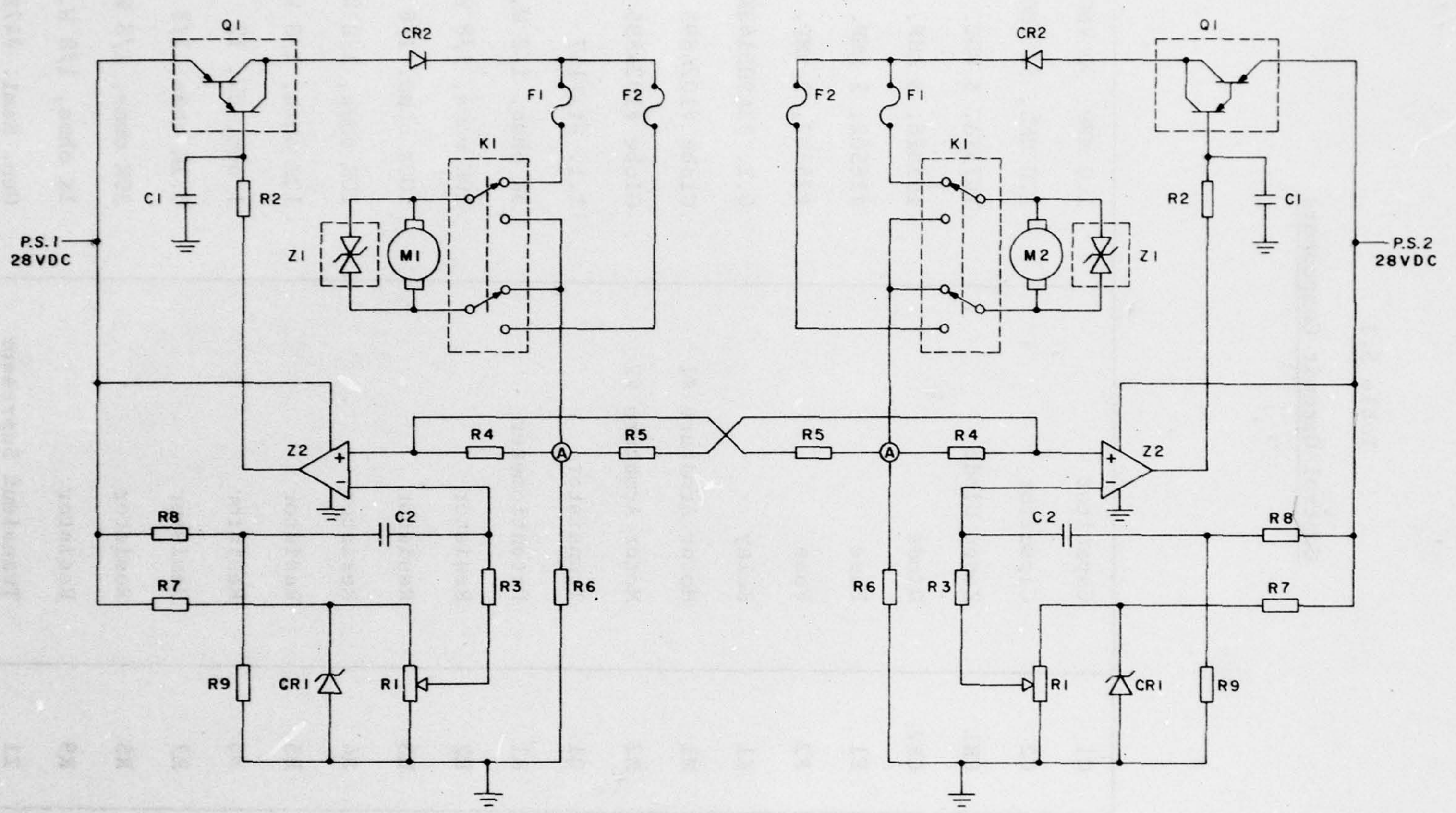
A control circuit was designed to eliminate all mechanical limit switches. Each armature of the tandem motor is energized with a constant voltage during an operating cycle, and an adjustable current limit allows the mechanism to reach a hard mechanical stop without damaging the motor or the mechanism. The control circuit in Figure 5.1 diagrams a reversing mechanism with tandem motors powered from two independent power sources. Either motor armature is capable of driving the mechanism independently, and the control circuits are completely redundant. Emperical data from the specific mechanism is used to determine the time interval of the applied voltage. Polarity reversing relays (K1) are energized only when the motors are operated in the reverse direction.

The cross coupled drive circuits allow control of the sum of the currents to both motors, thus limiting the maximum torque produced to a safe level. As indicated in Figure 5.1, resistors (R6) sense the motor current and drive the voltage comparators (Z2) through resistive adding networks (R4 and R5). When the voltage

Table 4.1

Motor Specifications

	Door Drive	Latch
Manufacturer	Globe	Globe
Type	BD	MM
Part Number	102A895	5A 3240
Motor:		
Voltage	27 VDC	24 VDC
Armature Number	8	11
Nominal Speed (no load)	15,100 RPM	6,500 RPM
Rated Load	1.6 oz. in.	0.8 oz. in.
Starting Torque	19 oz. in.	2.2 oz. in.
Nominal Current (no load)	0.29 amps.	0.08 amps.
Nominal Current (rated load)	1.0 amps.	0.28 amps
Geartrain:		
Gear Ratio	170:1	1528:1
Rated Torque	480 oz. in.	499 oz. in
Mechanical:		
Motor Diameter	1.5 in.	1.25 in.
Motor Length	3.875 in.	4.125 in.
Flange Dimension (square)	1.875 in.	1.50 in.
Overall Length	6.3125 in.	4.875 in.



TANDEM MOTOR CONTROL CIRCUIT

FIGURE 5·1

Table 5.1

Control Circuit Components

C1	Capacitor	1.0 MFD, 50 VDC.
C2	Capacitor	1.0 MFD, 50 VDC.
CR1	Zener Diode	1N751A, 5 VDC.
CR2	Diode	1N5626, 3 AMP.
F1	Fuse	#26502, 2 AMP.
F2	Fuse	#26502, 2 AMP.
K1	Relay	G.E. #3ASH5142K1
M1	Motor Armature #1	Globe #102A895
M2	Motor Armature #2	Globe #102A895
Q1	Transistor	T.I. #T1P147
R1	Potentiometer	5K ohms, 1/2 W, 5%
R2	Resistor	10K ohms, 1/8 W, 5%
R3	Resistor	100K ohms, 1/8 W, 5%
R4	Resistor	10K ohms, 1/8 W, 5%
R5	Resistor	10K ohms, 1/8 W, 5%
R6	Resistor	1 ohm, 5W, 1%
R7	Resistor	5.1K ohms, 1/8 W, 5%
R8	Resistor	30K ohms, 1/8 W, 5%
R9	Resistor	1K ohms, 1/8 W, 5%
Z1	Transient Supressor	Gen. Semi. #47Z1
Z2	Voltage Comparator	Nat. #LM339

at the summing node reaches the current limit set point voltage, the current can no longer increase, limiting the maximum torque produced to the predetermined level. Potentiometers (R1) are used to set the current limit.

Single failures in either control circuit, or one of the two power supplies, or an armature would not adversely effect the successful operation of the mechanism. However, a current limit circuit malfunction could destroy the motor and/or the gears. High reliability fuses (F1 and F2) are used to prevent damage, and actually provide operational redundancy for one subsequent reverse cycle. For example, a current limit circuit failure would cause F1 to blow when the mechanism reached the end of its travel in the forward direction, and the motor stalled. When the mechanism is driven in the opposite direction, motor power is applied through F2. The second fuse (F2) would not blow until the mechanism completed its cycle and the motor stalled.

Diagnostic monitors are included in the control circuit. Terminal 'A' in Figure 5.1 is a current monitor test point for each circuit. During functional checks the monitor confirms the operation of the redundant circuits on the test console. The signal is also compatable with 0 to +5 volt telemetry systems for in-flight monitoring.

Circuit protective components include power diodes (CR2), used to prevent shorted generator action in the event of a ground fault occuring in the control circuit, and transient suppressors installed across each motor armature.

6.0 MSMP MOTOR DRIVE SYSTESMS

All 10 control circuits for the MSMP sensor module systems are packaged in a 5.75-inch X 8.00-inch X 3.00-inch logic box with interface connectors to the payload harness or to test cables.

The prime battery pack (1.2 ampere hour, 28.8 volt, rechargeable ni-cad) is used exclusively for motor operation. A second identical battery is used for in-flight power transfer functions as well as redundant motor operation. External power supply operation of the motors is also possible through the payload control console.

An opening or closing cycle for any of the five mechanisms requires approximately 8 seconds; however, the current limit concept allows an additional margin of safety in the timing increment. The following is a typical sequence of events from the 32-function sensor module sequencer:

Function	Time (sec.)	Altitude (km.)	Increment (sec.)
Vent Door Open	70	60	15
Instrument Door Latches Open	97	107	12
Instrument Doors Open	110	122	12
Motor Polarity Relays	390	158	45
Vent Door Close	392	156	15
Instrument Doors Close	409	135	12
Instrument Door Latches Close	422	116	12

The motor polarity function switches all relays (K1 in Figure 5.13) for the duration of the closing cycles.

In addition to full cycle operation through the sensor module sequencer, the mechanisms can be selectively operated from the motor control console. Individual armatures can be energized from the test console, which also monitors operating current, stall current, redundant circuits and mechanism cycle times. Potentiometer outputs from the mechanism position monitors are also displayed on the console.

The following three sections describe the operation of the MSMP mechanisms. Drawings and technical reports which detail the sys-

tems are listed in Appendix A and Appendix B respectively.

6.1 MSMP INSTRUMENT DOORS

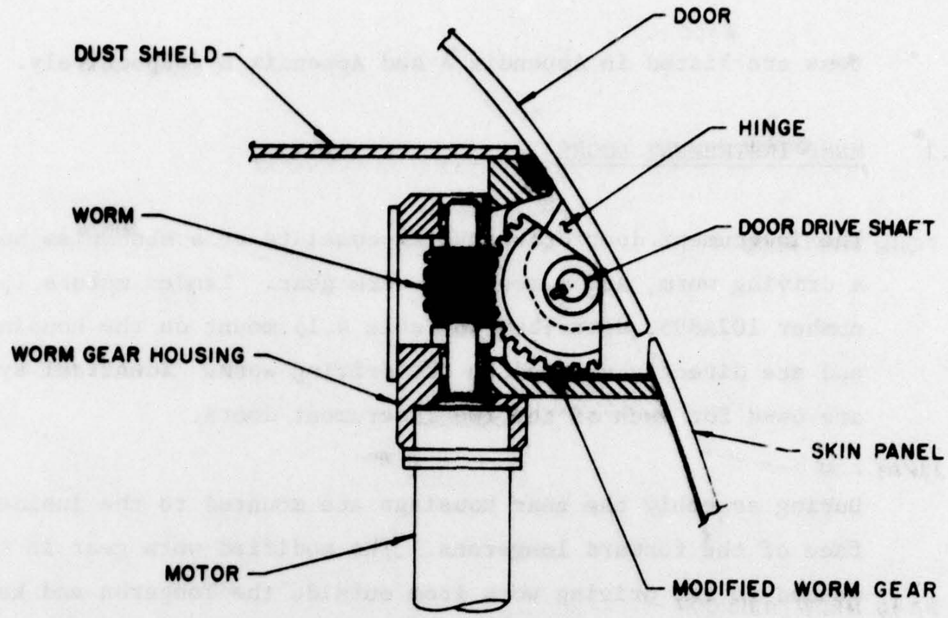
The instrument door drive system consists of a mechanism housing, a driving worm, and a modified worm gear. Tandem motors (part number 102A895, described in Table 4.1) mount on the housing, and are directly coupled to the driving worm. Identical systems are used for each of the two instrument doors.

During assembly the gear housings are mounted to the inside surface of the forward longerons. The modified worm gear is then meshed to the driving worm from outside the longeron and keyed to the drive shaft. A series of hinge brackets are mounted to the longeron cavity and to the interior of the instrument doors. Tubular shafts are installed through the hinge brackets and pinned to the drive shaft after the doors are aligned.

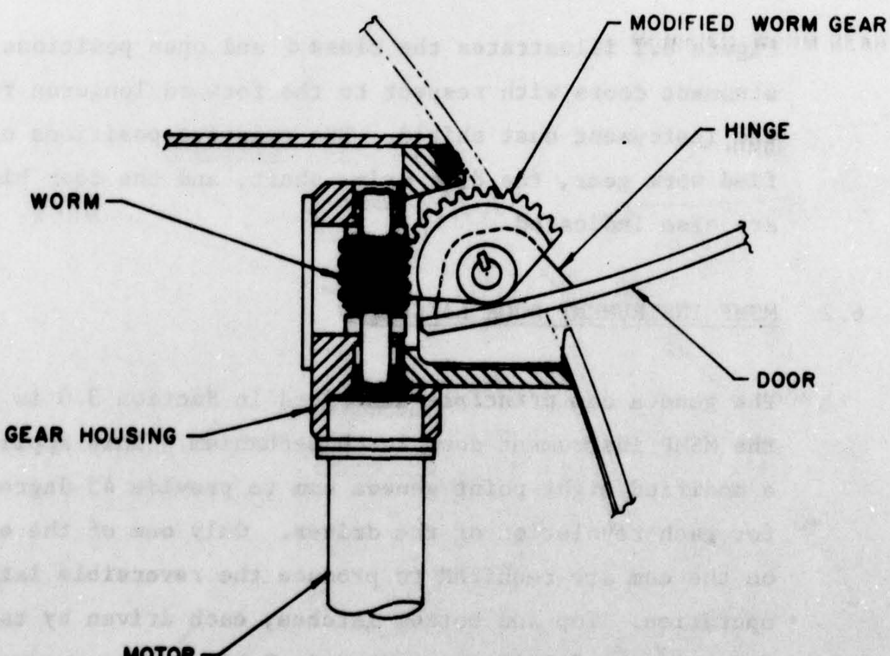
Figure 6.1 illustrates the closed and open positions of the instrument doors with respect to the forward longeron frame and the instrument dust shield. The relative positions of the modified worm gear, the door drive shaft, and the door hinge bracket are also indicated.

6.2 MSMP INSTRUMENT DOOR LATCHES

The geneva cam principle described in Section 3.0 is used for the MSMP instrument door latch mechanism. This application uses a modified eight-point geneva cam to provide 45 degrees of motion for each revolution of the driver. Only one of the eight points on the cam are required to produce the reversible latch/unlatch operation. Top and bottom latches, each driven by tandem motors (part number 5A3240, described in Table 4.1) secure the two instrument doors in the closed position and maintain a dust-tight



DOOR DRIVE MECHANISM
CLOSED POSITION



DOOR DRIVE MECHANISM
OPEN POSITION

FIGURE 6·1

seal along the longitudinal split plane of the doors.

Locked, engaged and open positions of the finger-like door latch mechanism are illustrated in Figure 6.2. The motor shaft is coupled directly to the driver, which is in an enclosed housing, along with the modified geneva cam, the cam follower, and mechanical stops for the mechanism. Motion of this reciprocating mechanism is as described is Section 3.0 for the engaged and open positions except for the mechanical stop in the open position. The locked position illustrated in Figure 6.2 indicates that the driver continues to rotate beyond the engaged position during a closing cycle, to the mechanical stop in the locked position. Timing of the motor cycle is not critical, since the current limit circuits are used in conjunction with the mechanical stops in both the open and locked positions.

6.3 MSMP VENT DOOR

Design of the MSMP sensor module was complete when the requirement for venting the payload was added. Modifications to the rear longeron provided the required 12-inch X 3.875-inch door in the sensor module directly opposite the experiment doors. Repackaging of the logic box allowed the addition of the two control circuits required to operate the tandem motors.

The vent door drive mechanism employs the same design theory as the instrument door latch mechanism. An eight-point geneva cam, modified to the two point configuration described in Section 3.0, provides the 45-degree reciprocal motion for the opening and closing cycles. Figure 6.3 illustrates the cam profile, the mechanism arrangement, and the linkage for the open and closed positions of the payload vent door. Tandem motors, identical to the latch mechanism, are used for this application. The motor shaft is coupled directly to the geneva cam driver. Cam follower stops are also provided to enable the constant voltage, current limit control previously described.

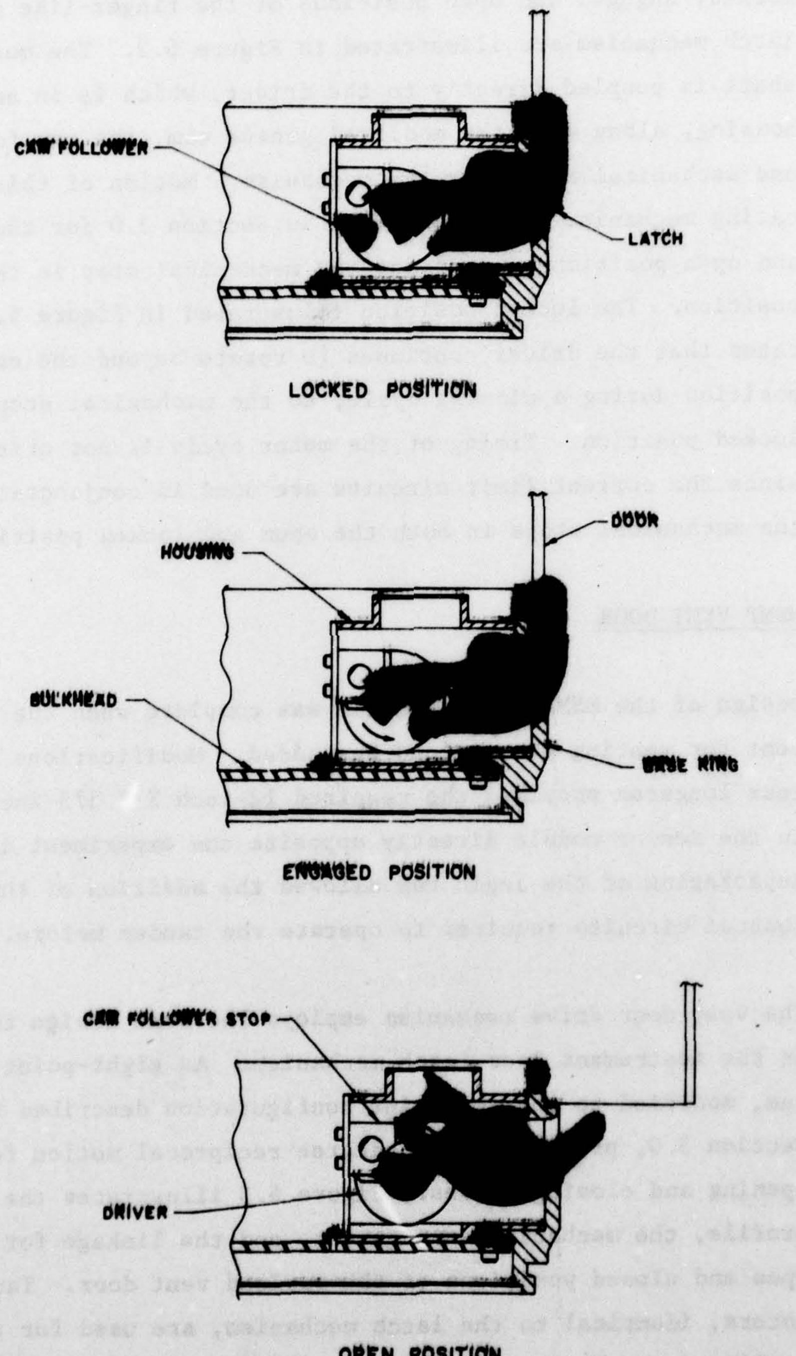

CAM FOLLOWER
LATCH
LOCKED POSITION
DOOR
HOUSING
BULKHEAD
BASE RING
ENGAGED POSITION
CAM FOLLOWER STOP
DRIVER
OPEN POSITION

FIGURE 6·2

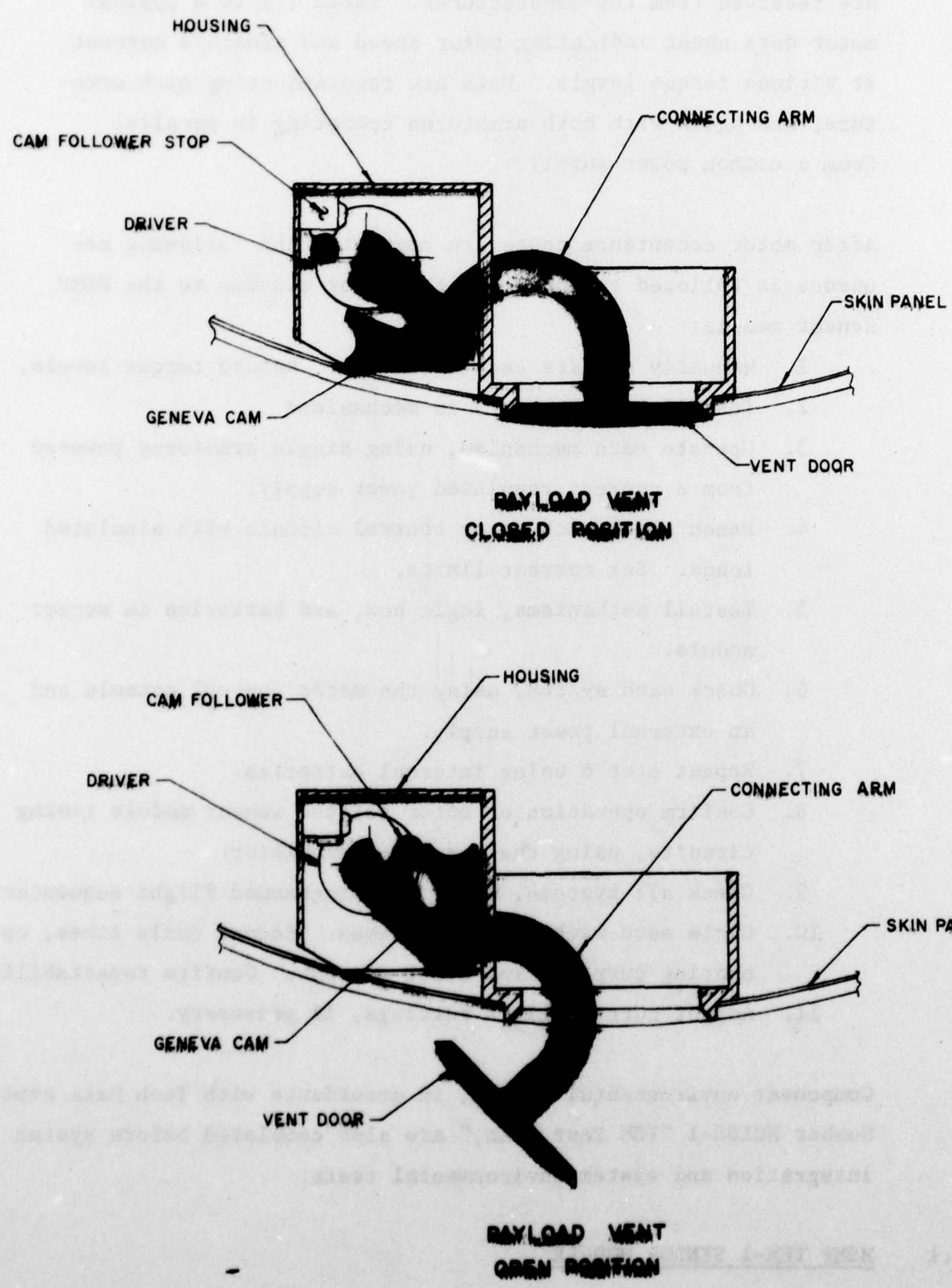

HOUSING
CONNECTING ARM
CAM FOLLOWER STOP
DRIVER
SKIN PANEL
GENEVA CAM
VENT DOOR
PAYLOAD VENT
CLOSED POSITION
HOUSING
CAM FOLLOWER
DRIVER
CONNECTING ARM
SKIN PANEL
GENEVA CAM
VENT DOOR
PAYLOAD VENT
OPEN POSITION

FIGURE 6·3

7.0 MSMP MOTOR DRIVE SYSTEM TESTING

All motors are individually checked on a dynamometer when they are received from the manufacturer. Table 7.1 is a typical motor data sheet indicating motor speed and armature current at various torque levels. Data are recorded using each armature, and again with both armatures operating in parallel from a common power supply.

After motor acceptance tests are complete, the following sequence is followed to integrate the motor systems to the MSMP sensor module:

1. Manually operate each mechanism. Record torque levels.
2. Install tandem motors in mechanisms.
3. Operate each mechanism, using single armatures powered from a current regulated power supply.
4. Bench check each motor control circuit with simulated loads. Set current limits.
5. Install mechanisms, logic box, and batteries in sensor module.
6. Check each system, using the motor control console and an external power supply.
7. Repeat step 6 using internal batteries.
8. Confirm operation of motor related sensor module timing circuits, using the sequencer simulator.
9. Check all systems, using the programmed flight sequencer.
10. Cycle each mechanism five times. Record cycle times, operating current, and stall current. Confirm repeatability.
11. Adjust current limit settings, if necessary.

Component environmental checks, in accordance with Tech Data Report Number NU108-1 "TEM Test Plan," are also completed before system integration and system environmental tests.

7.1 MSMP TEM-1 SENSOR MODULE

The first payload of the MSMP, TEM-1 (A24.609-1) was launched from

Table 7.1

Motor Test Data

Manufacturer: TRW Globe, Inc.

Part Number: 5A324

Serial Number: 5

Armature A:	Torque (oz. in.)	Current (ma.)	Speed (RPM)
	0	100	4.0
	100	120	3.9
	200	142	3.7
	300	170	3.5
	400	192	3.3
	500	220	3.1

Armature B:	Torque (oz. in.)	Current (ma.)	Speed (RPM)
	0	99	4.1
	100	123	3.8
	200	146	3.7
	300	170	3.5
	400	199	3.3
	500	225	3.1

Armatures A & B:	Torque (oz. in.)	Current (ma.)	Speed (RPM)
	0	96	4.3
	100	116	4.3
	200	145	4.1
	300	170	4.1
	400	202	3.9
	500	223	3.9

White Sands Missile Range (WSMR) on 10 November 1977. All motor systems functioned normally during integration, environmental, and pre-launch tests at WSMR. Current limit settings were established at 1.2 amperes for the experiment doors and 0.5 amperes for the latches and vent door.

Opening cycles of the vent door, latches, and instrument doors were as predicted during the flight. The vent door closed properly; however, the instrument doors did not complete the close and latch cycle. Data indicate that the sequencer function and the initial operation of the instrument doors were normal and the latches completed a closed cycle. Current monitors of the door drive motors indicate a stall condition was reached before the doors were actually at the mechanical stops. This condition is attributed to high aerodynamic forces on the doors due to a lower than predicted boost altitude and a confirmed malfunction of the attitude control system during flight.

7.2 MSMP TEM-2 SENSOR MODULE

In addition to the previously defined motor integration tests, extensive tests were conducted on the TEM-2 (A24.609-2) sensor module instrument doors to determine operating characteristics under various loads and at different current limit settings. Test data is reported in Quarterly Status Report Number 8 of Contract Number F19 628-76-C-0152. Current limit settings for the instrument doors were increased to 1.5 amperes, and the fuse values were increased to 2.0 amperes as a result of the tests. Latch and vent door settings remained at 0.5 amperes.

TEM-2 is scheduled for launch in January 1979.

APPENDIX A

RELATED DRAWINGS

Motor Drive Systems for Sounding Rocket Payloads

The following drawings include specific mechanical and electrical information on the MSMP motor drive systems and ground support equipment.

Mechanical Assembly Drawings:

D-3015-A	Door Latch and Lock Mechanism
D-3800-A	Door Drive Mechanism
D-3801	Door and Shaft Mounting
R-3814	Left Door and Left Front Longeron
R-3820	Right Door and Right Front Longeron
E-4008	Vent Door
E-4022	Structure and Skin Panels

Electrical Drawings:

EE-2296	Motor Control Wiring
ED-2358	Motor Interface Wiring
EC-2379	Motor Control Console Wiring
EE-2405	Instrumentation Control Console Wiring

APPENDIX B

RELATED DOCUMENTS AND CONTRACTS

Motor Drive Systems for Sounding Rocket Payloads

The following tech data reports include specific component information, test procedures and event sequences for the MSMP motor drive systems.

Tech Data:

NU107-6	TEM-1	Sequencer Format
NU107-7	MSMP	Telemetry and Calibration Data
NU107-11	MSMP	Logic Box Data
NU107-13	TEM-1	Flight Data
NU108-1	MSMP	TEM Test Plan
NU108-4	TEM-2	Sequencer Format

Previous Contracts:

F19628-67-C-0223	1 April 1967 to 28 February 1970
F19628-70-C-0194	1 March 1970 to 28 February 1973
F19628-73-C-0152	1 March 1973 to 31 May 1976
F19628-76-C-0152	1 June 1976 to present

APPENDIX C

PERSONNEL

Motor Drive Systems for Sounding Rocket Payloads

The following members of the Electronics Research Laboratory staff contributed to the work reported.

Lawerence J. O'Connor, Principal Investigator
Francis J. Bonanno, Mechanical Designer
Roger C. Eng, Mechanical Designer
Richard L. Morin, Research Associate, Engineer
Norman C. Poirier, Research Associate, Engineer
Frederick J. Tracy, Electronic Technician
Harry M. Tweed Jr., Electronic Technician